Drizzle and Entrainment in Coastal Marine Stratocumulus Clouds

Bruce Albrecht
Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Sciences; University of Miami
4600 Rickenbacker Causeway, Miami FL 33175
phone: (305) 361-4043 fax: (305) 361-4696 email: balbrecht@rsmas.miami.edu

Award#: N000149910036
http://orca.rsmas.miami.edu/monterey/

LONG-TERM GOAL

The long term-goal of this project is to provide an improved description and understanding of the effects of drizzle and entrainment on coastal marine boundary layer clouds that will establish a basis for developing, improving, and evaluating cloud and boundary layer representations in LES, mesoscale and large-scale forecast models.

OBJECTIVES

- Characterize vertical distribution of drizzle and how it relates to cloud circulations
- Investigate the relative role of cloud thickness and cloud turbulence levels on drizzle production
- Explore the mesoscale and convective-scale variability of drizzle
- Study the relationship of coherent eddies in the boundary layer to entrainment
- Document the structure and characteristics of entrainment circulations for a wide-range of stability and shear conditions
- Define the evolution of turbulence and coherent boundary layer structures during the formation and dissipation of coastal stratus

APPROACH

Observations from a suite of surface-based remote sensing systems were used to resolve the fine-scale microphysical and turbulence structure in coastal stratocumulus clouds. The centerpiece for the surface-based remote sensing is a short wavelength (3 mm) Doppler radar. Spectral processing of Doppler signals from this radar have been used for cloud microphysical and turbulence retrievals.. The Twin Otter research aircraft operated by the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) provided *in situ* observations for evaluating and improving the remote sensing retrievals and providing details of drizzle and entrainment processes. Integration and testing of a newly fabricated FM-CW 94 GHz radar on the CIRPAS Twin Otter provides critical development of airborne radar capability for studies of marine boundary layer clouds.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE
Drizzle and Entrainment in Coastal Marine Stratocumulus Clouds

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Meteorology and Physical Oceanography,,Rosenstiel School of Marine and Atmospheric Sciences;,University of Miami,4600 Rickenbacker Causeway,,Miami,,FL, 33175

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long term-goal of this project is to provide an improved description and understanding of the effects of drizzle and entrainment on coastal marine boundary layer clouds that will establish a basis for developing, improving, and evaluating cloud and boundary layer representations in LES, mesoscale and large-scale forecast models.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

WORK COMPLETED

Initial work on this project involved the development of hardware and analysis techniques for the June-July 1999 field deployment in Monterey. During this deployment the remote sensing systems were operated from a site on the shore of Monterey Bay near Marina, California. From 14 June to 9 July 1999 more than 100 hours of high-quality cloud observations were made with the UM 94 GHz radar. Doppler spectra were obtained at 3-second intervals and a vertical resolution of 30 m. Supporting observations were made continually with the microwave radiometer, two ceilometers, upward looking short-wave and long wave radiometers, standard surface meteorological instruments, and rawinsondes. The Naval Postgraduate School 915 MHz wind profiler provided continuous observations of low-level winds and boundary layer depth. A total of 20 flights were made with the CIRPAS Twin Otter to provide aerosol, cloud microphysics, and turbulence measurements in support of this and several other related projects. Descriptions of operations, instruments, synoptic conditions and results from initial analyses are available at the Drizzle and Entrainment Cloud Studies (DECS) Internet site http://orca.rsmas.miami.edu/monterey/ .

The spectral observations from the 94 Doppler GHz radar observations made during DECS have been processed to provide estimates of reflectivity (1st moment), mean Doppler vertical velocity (2nd moment), and spectral width (3rd moment) for all of the radar data collected. The radar observations have been combined with other remote sensing and in situ measurements to define the macroscopic structures of the clouds and their environment. A technique using a modified version of the Frisch et al. (1995) method have applied to all of the data collected during DECS to characterize drizzle. The moments data from the radar have been used to examine the relative role of cloud turbulence levels, the entrainment depth zone, and cloud thickness during drizzle and non-drizzle time periods. Mass flux profiles were obtained using techniques described by Kollias and Albrecht (2000).

An initial evaluation of a 95 GHz FM-CW that has been developed under an ONR sponsored SBRI, was made on the CIRPAS Twin Otter from 25 September to 9 October 2000. During this observational period techniques for using radar chaff to study entrainment processes and hygroscopic flares to stimulate drizzle processes were developed and tested.

RESULTS

Excellent cloud conditions were observed during DECS. Cloud top ranged from about 400-600 m with cloud base extending from near the surface to 200 m. Drizzle, mainly occurring during the night and in the early morning hours, was often observed in clouds that were more than 400 m thick. Drizzle and non-drizzle data periods were identified using the 1st and 2nd moment of the radar spectra. Drizzle was differentiated by a Reflectivity larger than –15 dBz and a mean Doppler velocity of less than – 0.5 ms^{-1}. These analyses include spectra of the vertical velocities observed in the cloud, vertical distributions of drizzle characteristics at 3-second intervals, calculation of the updraft and mass flux profiles using direct and statistical techniques, detailed time series of cloud macroscopic properties, cloud layer turbulence, and drizzle properties. On the days studied, observations typically extend from nighttime periods when clouds are relatively solid through the dissipation of these clouds during the day. The drizzle episodes observed during DECS-99 allowed composite profiles of drizzle characteristics to be developed (Fig. 1). Analyses indicate a suppression of resolvable scale turbulence during drizzle periods. This suppression of turbulence during drizzle episodes is consistent with the findings of Feingold et al., (1999) and contradicts the hypothesis that turbulence may enhance the formation of drizzle. A marked increase of drizzle production for clouds thicker than 400 m was observed. Further, these observations have also allowed us to capture the evolution of cloud layer structure and the entrainment zone as the cloud thins and dissipates. During the DECS observational period, there was about 80 hours of radar data collected when drizzle was not observed. This allowed for a detailed statistical description of the turbulence characteristics in the cloud. Composite statistics obtained through an analysis of ~50 hours of radar observations in non-drizzling stratocumulus clouds is shown in Figure 2. This figure shows composite vertical profiles of the resolvable scale vertical velocity variance and the variance within the radar sampling volume (unresolvable scale) when no drizzle is observed. These profiles provide a unique set of observations for comparison with LES results where both resolvable and unresolvable-scale variance fields can be obtained,.

IMPACT/APPLICATION

The cloud and boundary layer observations made during the field phase of this project represent a unique data set for studying the dynamics and microphysics of coastal stratus clouds. Doppler spectra obtained from the cloud radar represent the most extensive and detailed observations of this type in marine coastal stratus. The analysis of these data has advanced our understanding of the drizzle processes. To date the most relevant accomplishment has been a demonstration of the utility of using Doppler velocity spectra from a 94 GHz radar for characterizing drizzle and entrainment in coastal stratus clouds. The extensive and unique set of radar observations made during DECS provide the basis for developing comprehensive statistics on drizzle characteristics, examining entrainment and drizzle processes, and developing observing strategies and analysis techniques for advancing the use of mm-wavelength radars for boundary layer cloud studies. In the future studies, these techniques will be applied to measurements made with the ProSensing radar developed for use on the CIRPAS Twin Otter research aircraft.

TRANSITIONS

The techniques developed to retrieve cloud microphysics and turbulence from the radar observations provide a basis for further development and application of similar retrieval techniques that can be used with the 94 GHz radar developed under an ONR initiative. The cloud and boundary layer observations made during the field phase of DECS are available for comparison with the boundary layer and cloud structure from NRL COAMPS simulations made in the area of interest.

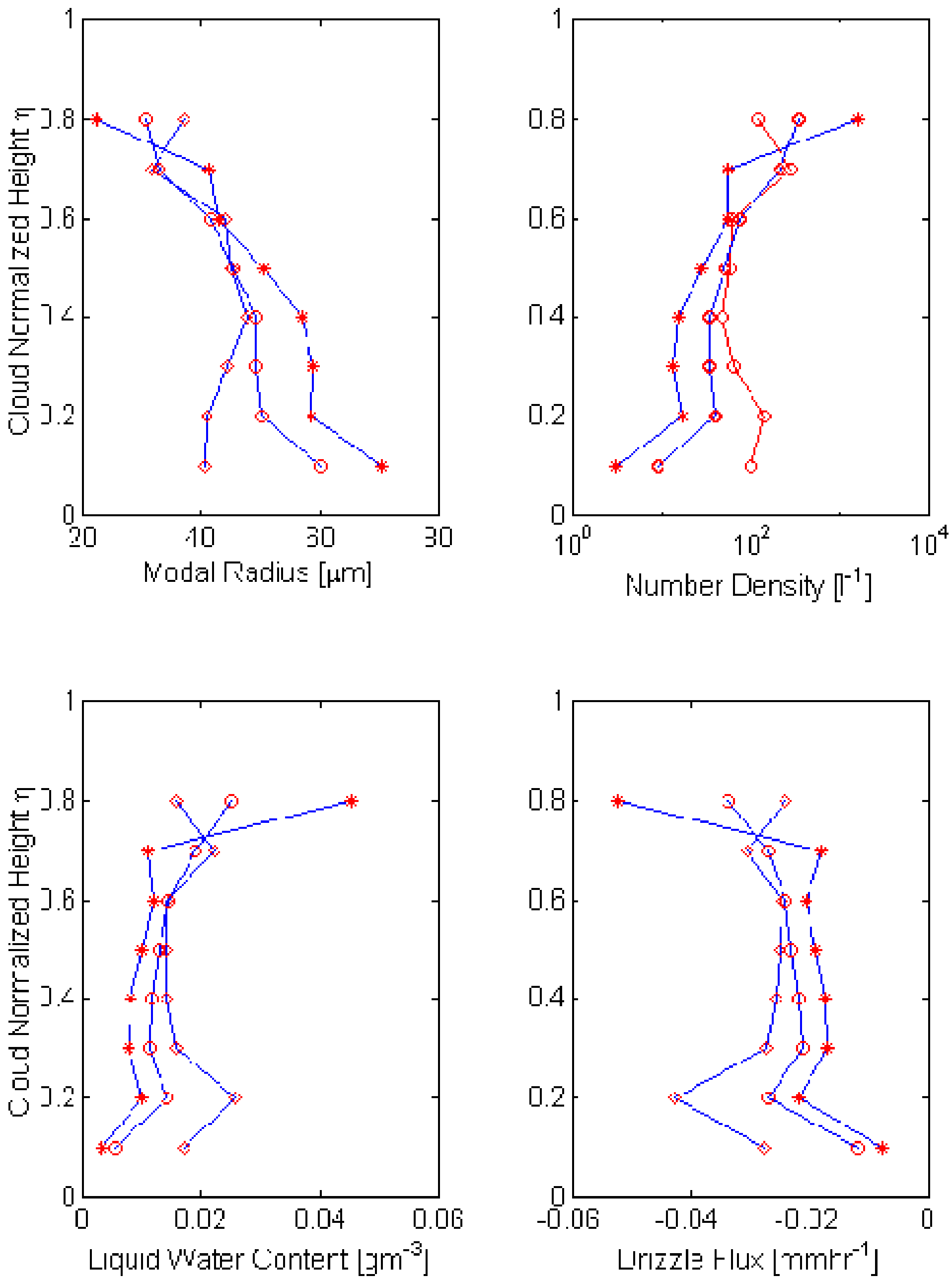

Figure 1: Composite profiles of drizzle properties (modal radius, droplet concentration, drizzle liquid water content, and drizzle flux) obtained by applying modified version of Fritch et al. (1990) technique to drizzle events analyzed from DECS radar data. The composite for all events analyzed (open circles) are compared with day- time (stars) and night-time (open triangles) composites obtained on 24 June 1999. Profiles are obtained on a height scale non-dimensionalized using cloud base and cloud top as the bottom and upper boundaries.

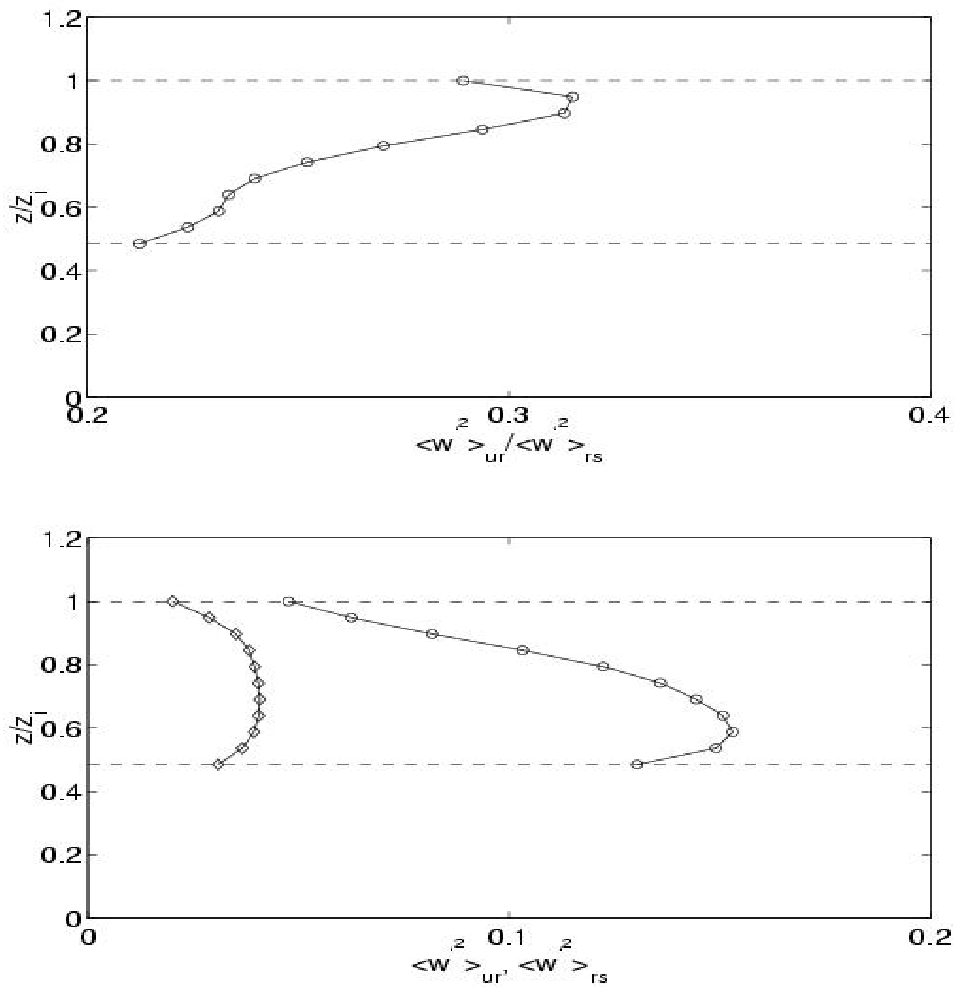

Figure 2: Composite profile (top panel) of the ratio of the un-resolvable scale vertical velocity variance (within the radar sampling volume) to the resolvable-scale variance (calculated from individual 3-second vertical velocity profiles) showing a maximum value of 0.32 near cloud top and decreasing to 0.22 near cloud base. Composite profiles (bottom profile) of the un-resolvable scale and resolvable scale vertical velocity variance from ~50 hours of data obtained during DECS-99 under conditions where drizzle is negligible. Maximum unresolvabe scale vertical velocity variance is observed just above the middle of the boundary layer while maximum unresolvabe scale vertical velocity variance is observed near the middle of the cloud layer.

RELATED PROJECTS

Several scientists were involved in related projects during the Monterey coastal cloud experiment. Qing Wang from the Naval Postgraduate School was heavily involved with the CIRPAS Twin Otter in support of a NSF study of the interaction between coastal flows and marine stratocumulus. Dean Hegg of University of Washington and Rick Flagan of CalTech were involved in aerosol studies using the CIRPAS aircraft during DECS. Graeme Stephens headed a NASA/DOE project in support of CloudSat, a NASA project to use a 94 GHz radar in space. In support of this project, an airborne cloud radar was operated by the University of Mass on a DOE Twin Otter during DECS. This aircraft flew coordinated patterns over the CIRPAS Twin Otter, which was making cloud microphysical measurements in the cloud.

SUMMARY

The use of a Doppler millimeter wavelength radar for remotely characterizing drizzle and entrainment in coastal stratus clouds has been demonstrated. These characterizations provide a description of the vertical structures within clouds that is unattainable from conventional instruments and provides a new understanding of processes critical to the formation, maintenance, and dissipation of low-level clouds. This study facilitates the deployment and application of the ProSensing airborne millimeter wavelength radar. This air-borne capability will provide opportunities to study boundary layer clouds over marine areas that cannot be accessed easily by surface-based platforms. This study has aided in the establishment of a well-recognized center for the application of mm-wavelength radars to meteorological scientific studies at the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences.

REFERENCES

Feingold G., A. S. Frisch, B. Stevens, W. R. Cotton, 1999: On the relationship among cloud turbulence, droplet formation and drizzle as viewed by Doppler radar, microwave radiometer and lidar. *J. Geophys Res-Atmos,* **104** (D18): 22195-22203.

Frisch, A.S., C.W. Fairall and J.B. Snider, 1995: Measurements of stratus cloud and drizzle parameters in ASTEX with a K_A-band Doppler radar and microwave radiometer. *J. Atmos. Sci*., **52**, 2788-2799.

Kollias, P and B. Albrecht, 2000: The turbulence structure of a continental stratus clouds from 94 GHz Doppler radar observations. *J. Atmos. Sci.*, 57, 2417-2434.

PUBLICATIONS

Fritz, S., B. Albrecht, and P. Kollias, 2000: Characteristics of Drizzle in Coastal Stratocumulus Clouds. Preprint. 13th International Conference on Clouds and Precipitation. 14-18 August, 2000. Reno Nevada. 823-826.

Fritz, S., B. Albrecht, and P. Kollias, 2001: Drizzle Characteristics from a Surface-Based 94 GHz Radar. Preprint. 30th Conference on Radar Meteorology. 18-23 July, 2001. Munich Germany. 632-634.

Kollias, P., B.A. Albrecht, B. J. Dow, 2001: Turbulence and Microphysical Retrievals Using MM-Wavelength Doppler Spectra. Preprint. 30th Conference on Radar Meteorology. 18-23 July, 2001. Munich Germany. 376-378.